Benthic diatom investigations of some Hungarian streams have been carried out in order to find reference sites in assistance to the ecological quality analysis of the different river types according to the Hungarian river typology.

On the basis of the coevaluation of biological and chemical parameters, Kemence stream seems to be the appropriate reference site for the classification of the highland, siliceous rivers of Hungary. However, further investigations are needed for the selection of reference sites for the other types of Hungarian river typology. This is the most difficult in the case of lowland rivers, which are exposed to more severe anthropogenic impacts. Important is the question which biological parameters should be investigated and considered when assessing the ecological condition of our waters. In the United States, e.g., the assessment of the relative abundance of *Achnanthidium minutissimum* is quite widespread (Stevenson et Bahls 1999), the extent of which indicates the level of disturbance. The use of this method is hampered, on one hand, by the fact that *A. minutissimum* is an early coloniser species which means that if we do not take samples from mature periphyton, we might find it dominant simply because of that, and, on the other hand, that distinguishing between the species varieties is not always unambiguous under light microscope because of its small size, and these can have different ecological needs. It is also recommended to calculate species richness, diversity and evenness (Stevenson et Bahls 1999), but based on our investigations these parameters are not in correlation with water quality.

Investigation of other diatom features such as tolerance and sensitivity, some autecological parameters (as it was applied and recommended by Fore and Grafe 2002 for investigating the reaction of diatom associations to anthropogenic disturbances) might also be useful in completing the water quality analysis of rivers, however, these methods need further investigations.

Some of the indices (EPI-D, IPS, IBD) calculated with the software Omnidia are suitable for the classification of our rivers, but the investigation of more rivers, flowing through different types of stone are necessary to choose the appropriate indices. The reason for this is that the different indices work with a different register of species and obviously those indices will prove to be suitable the species register of which shows the highest similarity to the diatom associations of the certain water type.

Key words: benthic algae, reference conditions, diatom indices, Water Framework Directive
INTRODUCTION

Benthic diatom communities react very quickly to disturbances of the water (e.g. to changes in the physicochemical conditions of the water or to the pollution affecting the catchment area), very often by changes of their species composition or diversity, which can vary from species rich to monotonous communities. Because of this characteristic, benthic diatom communities are a useful tool in detecting anthropogenic impacts.

Investigation of benthic diatoms is recommended by the Water Framework Directives (Water Framework Directive, European Parliament 2000 directive, 2000/60/EC), they are considered key organisms in the ecological quality analyses of watercourses and have been applied for more than a decade in several countries of Europe (in Austria, Switzerland, Germany, Belgium, France, Poland, Finland, Luxemburg, United Kingdom, Spain, Portugal, Italy). One of the main goals of the WFD is to assign the extent of difference to which ecosystems differ from the high ecological status, where there are no or only very minor anthropogenic alterations (reference ecosystems).

Diatoms are an important group of water ecosystems, they form a large part of the benthos (often 90–95%) that is why they could become an important part of water quality monitoring. A huge advantage of the benthic diatoms is that they can be found in every surface waters, at any time. Furthermore, in form of preserved preparates or acid digested sample slides, collected diatom samples can be preserved for an unlimited period of time, thus the can be reinvestigated whenever necessary. It is also incomplecated to decide what to consider an individual. However, a disadvantage of investigating diatoms is that it requires thorough taxonomic knowledge.

Sampling is regulated by detailed standards (CEN-ISO) in order to enable a uniform watercourse qualification system in the countries of the European Union. For precise ecological classification of watercourses we have to define the reference conditions for each water type (in connection with the river typology based on the physicochemical and hydromorphological characteristics of the river). Conditions without or with only insignificant anthropogenic impact can be regarded as reference conditions.

The aim of this work was to investigate benthic diatoms of streams with different typologies (Somlyódi and Szilágyi 2004) in order to find reference sites to support the ecological qualification of rivers. This was the first thorough investigation in Hungary of the kind where not only diversity, species composition and chlorophyll content were determined but the data were also analysed with a benthic diatom based water qualification system, the use of which is novel in Hungary.
The state of the benthic diatom based river monitoring in different European countries before the publication of the EWFD

Up to now, the state of the benthic diatom based water quality monitoring in Europe has not been reviewed in Hungary, that is why we considered it important to fill this gap. The review has been prepared on the bases of the works of Prygiel et al. (1999) and Whitton et al. (1991, 1996), respectively, an additional source of information is marked in the case of some countries.

United Kingdom

Development of indices appropriate for river monitoring was started in the United Kingdom in 1989, with the formation of the National Rivers Authority. The Urban Wastewater Treatment Directive of the EU requires the identification of stretches of rivers, which are vulnerable to eutrophication. The Trophic Diatom Index was developed parallel to this work. Methodological studies about the investigation, sampling and identification of macroalgae already started in the sixties and the experiences of these works were summarised in a standard methodology book in 1987. Besides constructing the TDI, a number of algological investigations have been and are carried out in different parts of the United Kingdom, the monitoring of potentially toxic or hazardous algae, cyanobacteria, phytoplankton and picoplankton studies and their fluorimetric analyses.

Italy

Algal-based water quality monitoring started only in the eighties in Italy. Since then, researchers have primarily been concerned with the development of appropriate methodology. Two different eutrophication/pollution indices were constructed, one of them is diatom- the other one is macroalgae-based. The abbreviated names are EPI-D and, EPI-M, respectively. The use of macroscopic algal based indices are more practical in the case of shallow and transparent waters, allowing direct observation in the field. This method is appropriate for rapid, preliminary assessment. In contrast to the macroalgae, diatoms are distributed along the whole basin of rivers, furthermore, they are better known from taxonomic and ecological point of view thus enabling a higher degree of precision when defining the trophic state and level of pollution. EPI-D index works on the basis of nutrient supply, organic pollution, total dissolved ion concentration (first of all chloride) of the water and the sensitivity of diatoms towards these parameters. Currently, the research is more likely a fundamental research with the aim of developing a well-functioning, widely applicable water qualification system for the future. Four watercourses
have been investigated in Italy using EPI-D index and measuring physico-chemical parameters at the same time. In most cases, the index value showed positive correlation with the biological oxygen demand (BOL), phosphate, inorganic nitrogen, conductivity and chloride concentration and negative correlation with the oxygen concentration. In spite of these promising results, further work is being carried out to improve the indices.

Spain

Throughout the eighties and nineties, benthic diatom samplings were carried out on the River Ter in order to analyse the water quality. Data were processed with the help of parallel water chemistry data and principal component analysis. The researchers drew the conclusion that benthic diatoms are well applicable for the water qualification of watercourses.

Austria

In Austria, two major applied projects have been completed since 1995: one was the analyses and control of a regional diatom dataset, the other was the establishment of a checklist of benthic algae based on data from the previous 15 years, in which abundance, frequency, saprobic value and indicating weight was given for most species. On the basis of this list, a regional trophity index (ROT) was developed, which works with macro- and microalgae, however it can be used exclusively on the basis of diatoms, too. Water quality monitoring has been going on in Austria for several years, the surveys are on the first place diatom-based, but sometimes they are based on the analyses of the whole periphyton community.

Germany

A Red List for algae was completed in Germany in 1996, which comprises all the algae taxa found in Germany; furthermore, it contains autecological information. Most of the monitoring methods in Germany are diatom-based. The differentiating species system is used for monitoring organic pollution, salinity is estimated by the Ziemann halobic index, the trophic state by the Hofmann- and Schiefele-Kohmann trophity indices and acidification is monitored with the Diatom Assemblage Type Analysis of Coring and with the SHE index. SPI index is also applied and so is a combined system for measuring both trophity and organic pollution.

Although uniform water quality monitoring directives exist for the whole of Germany, on one hand these specify only a narrow range of analyses...
(heterotrophic organisms and water chemistry parameters), on the other hand it is difficult to render the theory into practice, mostly because of the lack of a well-trained staff. Training courses are not performed either. All in all, uniform water quality monitoring was not in a very progressed state in Germany in 2000.

Finland

Before the nineties, monitoring of Finnish watercourses was mainly based on the measurement of chemical variables. However, as the use of water quality algal indices was spreading throughout Europe, investigations of such kind has also started in Finland. Diatom index values were calculated from several data sets collected since 1970s and additional sample sets gained from natural and artificial substrata. The indices of the software “Omnidia 2” were tested. The index values were correlated to water chemical parameters. Since the humic acid content of the Finnish waters is generally high and it also has an effect on the chemistry of the water, this has to be taken into consideration when evaluating the index results.

On the basis of preliminary investigations, Finnish researchers have concluded that several indices developed in Europe are most probably well usable in Finland, too. Nevertheless, they work with several indices at the same time and because of the special character of the Finnish waters, the results are handled with caution.

Portugal

According to the present Portuguese law issued in 1991, only physical, chemical and a few bacteriological variables are to be measured for routine water quality evaluation. Therefore, diatom based monitoring in Portugal is sporadic and not uniform. Studies of this kind are being carried out mostly by university research groups and are quite recent. During the seventies and eighties the Pantle-Buck, Zelinka-Marvan, later the Descy, Coste and Shannon-Weaver indices were used on several rivers with variable results. In the northern part of the country, chlorophyll-a, phaeopigment, diatom density and Carlson trophy index were used for water qualification. Recently, the indices of the software Omnidia has also been tested and showed promising results, although some authors have suggested some modifications in the autecological data of the diatoms, suiting the Portuguese conditions. A study has also been carried out on the algological monitoring of heavy metal pollution. On the basis of the last three decades’ algological investigations, researchers are able to give a general overview on the water quality of Portu-
guese rivers, however, the monitoring is still not uniform and satisfactory, partly because the access to the regulations about it is fairly difficult. For the future, researchers suggest parallel investigations of several parameters (such as physical, chemical, bacteriological, macrozoobenthos, fish, biological indices, ecotoxicological tests, heavy metal monitoring), but they conclude that for routine monitoring, a combination of algological investigations permits a realistic water quality assessment.

**Benelux States**

Until recently, algae have only occasionally been used by the administrative bodies responsible for river biomonitoring in Belgium and Luxembourg. Nevertheless, algology has great tradition in Belgium: it was among the first European countries to use benthic diatoms for monitoring river water quality. Development of diatom indices for water quality analysis was already started in the 70s in the Vallon part of the country. There were detailed diatom investigations on the Flamish part of the country, too, even some diatom indices were put to test, but the official water management bodies do not apply them for water quality analysis. In Luxembourg, algology has been a rather neglected field, the use of diatom indices has also been sporadic.

Based on the investigations of the last 25 years – which have been carried out by universities and research institutes rather than by governmental water management bodies – we have a certain amount of information about the water quality of several rivers of these three countries, furthermore, these research activities contributed to our knowledge about the autecology of diatoms and to the development of diatom indices. In spite of this, benthic diatom based water quality monitoring is disregarded from the side of the governmental water management bodies.

**France**

Periphytic diatom investigations have been carried out in France since 1980, several indices have been constructed here. Since 1991, water quality monitoring is being continuously performed, in which process a considerable network has been made for mapping the water quality of watercourses. In the past few years the French water authorities were working on the development of an index (IBD), which can be used throughout the country as a routine method. Before the index became standardised, they made steps to facilitate the use of these indices: a CD-ROM has been created for the light microscopy identifications, and not only have the indices been integrated into Omnidia,
but also a special software for calculating the indices was designed (Omnibio). A group of specialists facilitate the samplings and identification.

Slovakia and Czech Republic

Phytoplankton and phytobenthos investigations have continuously been carried out at 244 sampling points, on the basis of the Slovakian national standard, which considers first of all chlorophyll-a content, cell number and saprobity index values. Because of this, these countries possess information about the water quality of their most important rivers.

The integration of EU standards into the national standards has been started. The chlorophyll concentration measurement and *Scenedesmus* inhibition tests have been put into practice, while the harmonisation of the other EU standards is under way. In Czech Republic, only the chlorophyll concentration of phytoplankton is being continuously measured.

Estonia

Algological investigations were started in 1991 in Estonia, with a seven-year project. In 1994, a new project with extended hydrobiological, chemical, biological investigations was started in order to get an idea about the water quality of 25 rivers. Target of algological investigations were mainly the pigment content, individual number and dominant species of phytoplankton. Diatom flora of rivers has been less frequently investigated in Estonia, benthic diatom investigations have been carried out only in seven rivers. In 1995, 1998 and 1999, benthic diatoms and chemical parameters of three rivers were investigated in order to make water quality analyses. Based on these studies benthic application of benthic diatom communities have been proposed for monitoring water quality. The trial of benthic diatom indices will happen in future (Vilbaste 2001).

Poland

Monitoring of surface waters has been carried out in Poland since 1960, although the monitoring system was only unified in 1990. At that time, three categories have been defined on the basis of physical, chemical and biological parameters such as colititer, chlorophyll content and Pantle-Buck saprobity. Based on their investigations Polish researchers have information about the water quality of each of the more important waters. Currently they are working on the completing of the monitoring system, which would also mean wider
scale algological surveys, that is diversity and structure analyses of planktonic and benthic algae. Introduction of the diatom indices (based on Omnidia software) is proposed. With the aid of algological, chemical and physical data of 38 rivers, Omnidia indices have already been tested. The indices SPD and GDI have been found the most appropriate for Polish conditions. All in all, methodological rules and preliminary studies for river water quality monitoring according to the norms of the European Union have been completed in Poland. As for diatom investigations: in the northern part of the country, water quality of several rivers has been analysed on the basis of the Omnidia indices and the applicability of the indices has also been tested. Index values and the composition of benthic diatom communities were correlated and statistically compared to chemical parameters. Certain indices and the structural analysis of benthic diatom communities were found to be applicable.

**Romania**

There is basically no algal-based water quality monitoring system, or plans for the development of it in Rumania. Also very few algological information from before stays at our disposal.

**Hungary**

Benthic algological investigations have been sporadic since the 1960s in Hungary. These studies focussed first of all on large rivers. Although benthic diatom investigations were not regular before that time, either, but they were focussed on smaller streams and watercourses (Cholnoky 1933, Szemes 1931, 1957, Tamás 1957, Uherkovich 1976). Regular benthic diatom investigations have been carried out in the Szigetköz branch system of the Danube since the 90s, where mainly the effects of the dam construction and that of the diversion of the river on the wildlife have been studied. This can be considered more to be a diversity study, since changes of the species composition of benthic algae have been tracked (Buczkó and Ács 1992, 1994, 1996, Ács and Buczkó 1994, 1996, Buczkó et al. 1997). Regular investigation of benthic diatoms of the Danube started in 1984 at Göd (Ács 1988, Ács and Kiss 1991a, b, 1993a, b, Makk and Ács 1996, 1997, Ács 1998, Makk et al. 1999, 2003, Ács et al. 2000). Lately, these investigations have been extended to the source area, to the German, Austrian and Slovakian stretches and some larger side arms of the Danube (Ács et al. 2003). Regular benthos investigations were also carried out in the Soroksár-Danube in the second hal of the 90s (Barreto et al. 1998, Ács et al. 2000, Szabó et al. 2001). Sporadic benthic diatom studies, where diatom indices were used for the quality analysis of the water, have also been carried out (Szabó et al. 2004).
In connection with the cyanide- and heavy metal pollution of the River Tisza, we drew the conclusion that indices are not appropriate to indicate toxic pollution (Kiss et al. 2002). However, in several other cases, they are well applicable, first of all for the analysis of inorganic nutrient overload (Ács et al. 2002, 2003).

About diatom indices and the software Omnidia

The software Omnidia (Lecointe et al. 1993) is a computer programme, with the help of which 14 different diatom indices can be calculated. Furthermore, it calculates diversity and evenness values and it also contains four ecological qualification scales. Most of the diatom indices are based on the weighted average of the Zelinka-Marvan equation (1961). The database of the programme comprises 6500 diatom taxa (together with synonyms), out of which the ecological sensitivity and indicator values are characterised for 1800. Lowe’s (1974) summary of the ecological needs and pollution tolerance of freshwater diatoms served as a firm basis for this database. This author described the pH-, temperature-, water current-, organic matter-, nutrient-, and salt-needs, seasonal distribution and life form of 298 taxa, where these were known from literature data. This database has been developed since then, newer and newer versions are created with more and more species and information. Currently, Omnidia version 3 is the latest version, it was published in 1999. The abbreviated names (list of abbreviation is annexed to the program) and relative abundances of the taxa observed in the sample has to be included in the program. This can be conducted directly while counting the samples or the data can be imported from excel (as long as the data are in the appropriate form there). The software has two main parts, a taxonomic database and a part for the storage of information about our samples. In the taxonomic database, search can be performed on the basis of family, genus or species names (and here, we also have the possibility to modify the data about the species). It visualises several information about the species such as the name, synonyms, describer, taxonomic classification (family), the sensitivity and indicator values given by the different indices, the van Dam (1994) and Hofmann (1994) ecological values, the Denys (1991) habitat- and life form classification and in many of the cases light microscopical image with scales. The other main part of the program pertains to the samples. Here we can register our data about each sample, e.g. slide number, name of the sampled water body, sampling point and time, and we can also store some additional information about the sampling point (water temperature, distance from the source, hydrological parameters, additional remarks). Later, when we recall the data, the species list appears with the appropriate relative abundances, the values of the indices listed below, diversity, evenness, species number, number of the counted valvas (these
data can also be printed of course, either directly or to file. Here we can also get
the ecological characterisation of the samples on the basis of Lange-Bertalot
(1979), Denys (1991a, b), Van Dam et al. (1994) and Hofmann (1994).

Lange-Bertalot (1979) identified the ecological preferences of 100 widely
distributed and frequently abundant freshwater diatom species and he classified
them into different saprobic categories. He constructed three classes: re-
sistant, sensitive and ubiquist. The quality class of a sampling point is defined
by the relative abundances and saprobic categories of the identified taxa.
Denys (1991a, b) diagnosed the autecologies of 980 fossil taxa regarding the
salt content, pH, trophic state, saprobity, nitrogen uptake, oxygen demand
and water current preferences. Van Dam et al. (1994) determined the pH, nitro-
gen, oxygen, salinity, humidity, saprobic and trophic preferences of 948 fresh-
water and brackish water species. Hofmann (1994) performed similar studies
on several, mainly Bayer alpin lakes alcalic lakes.

The diatom indices used in the software Omnidia (with their abbrevia-
tions, after Luc et al. in press): SHE = Schiefele-Schreiner index (Steinberg and
Schiefele 1988, Schiefele and Schreiner 1991). This index works similarly to the
system of Lange-Bertalot (1979) but it was modified to the rhithral part of
rivers. It categorises 386 species into 7 groups according to their trophic state
and pollution resistance. WAT = This is the index by Watanabe (Watanabe et
al. 1988), the other name of it is DAiPo (Diatom Assemblage Index to organic
pollution). It classifies 226 taxa on the basis of their pollution tolerance (biolog-
ical oxygen demand). The basis of the following indices is the Zelinka-Marvan
(1961) equation: DES = Descy’s (1979) index, it classifies 106 species into 5 sen-
sitivity classes. SLA = the index of Sladeček (1986), it classifies 323 species into
5 sensitivity classes. L&M = this is the index by Leclercq and Maquet (1987), it
classifies 210 species into 5 sensitivity categories. ROT = Rott’s index (Rott et al.
1997), it has five sensitivity classes, primarily on the basis of saprobiological
preferences. IDAP = Diatom Index Artois-Picardie (Prygiel et al. 1996), this in-
dex was developed for the French Artois-Picardie region, it classifies the spe-
cies into five categories. IPS = Specific Pollution Sensitivity index (Coste in
Cemagref 1982), it uses every species from the database and categorises into
five sensitivity groups. GDI = Generic Diatom Index: (Rumeau and Coste
1988, Coste and Ayphassoro 1991). This index uses five sensitivity classes, for
which diatoms needs to be identified only at the genus level. This user-
friendly index was developed to facilitate the practical work of water authori-
ties. It uses every freshwater species and genera from the database. IBD = in-
dex Biologique Diatomées (Biological diatom Index, Lenoir and Coste 1996,
Prygiel and Coste 1998, 2000). This is also primarily a practical index, as it
treats the morphologically related taxa as one group and composes so-called
associated taxa. This index was also standardised from sampling through
sample preparation to microscopical analyses (identification and enumeration) (AFNOR 2000). It uses 209 species from the database. CEE = the index of Descy and Coste (1991), it uses 208 species. EPI-D = Eutrophication Pollution Index Diatoms (Dell’Uomo 1996), it classifies into five categories. TDI = Trophic Diatom Index (Kelly 1998, Harding and Kelly 1995), it classifies into five sensitivity categories. This index is widely used in the United Kingdom, it is appropriate for the qualification of strongly polluted waters, where wastewater input is significant. The PT % (Pollution Tolerant Taxa %) is connected to the TDI index, it gives the percentage of pollution tolerant taxa in the given sample.

**MATERIAL AND METHODS**

Based on the Hungarian river typology system “B” of the Water Framework Directive, we chose a calcareous stream above 200 m altitude with rough river bed substratum (Bán-Szalajka stream complex in the Bükk Mountains), two siliceous streams above 200 m altitude with rough river bed substratum (stream complex Szén-Török-Morgó in the Börzsöny Mountains, which flows into the Danube as lowland river, and stream Kemence in the Zemplén Mountains, which is a stream of mid-altitude throughout its entire stretch), and a lowland, siliceous stream with fine river bed substratum (stream Nagyberki in the Somogy Hills), on sites that are not significantly affected by anthropogenic impacts, in order to look for reference sites with the aid of benthic diatom investigations.

The source of the stream complex Bán-Szalajka is in the Bükk Mountains, that of stream Szalajka is below Istállós-kő, that of stream Bán is below Bályányos. The two streams unite at Nagyvisnyó, forms the Lázbérci reservoir below Dédestapolcsány, then it flows into River Sajó below Vadna. The length of the two streams is altogether 43 kms. We took samples from stream Szalajka on the stretch above the trout-breeding farm close to the source (SzF) and on the stretch below the trout-breeding farm (SzA). We took samples from stream Bán close to the source (BF), before the Lázbérci reservoir at Dédestapolcsány (BD) and at the mouth (BT).

Stream Morgó (or Török), which originates from several sources at Királyrét in the Börzsöny Mountains, flows into the Danube at Kismaros. We took samples on 29 September 2003 from one of its sources called Szén stream (Sz), from Morgó stream below Szokolya (MSz) and close to the mouth at Kismaros (MK).

Stream Kemence originates in the Zemplén Mountains, above Rostalló and flows into river Bózsva after Kishuta, after 10 kms, basically without touching any bigger settlements. At Kőkapu, in 3 km distance from the source,
a small fishing pond was constructed (pond Áfonyás) with the aid of a barrage. Stream Kemence was divided and a part of its water flows into this pond and again, water from the pond is discharged into stream Kemence. Samples were taken on 22 May 2004 close to the source (KF), directly before pond Áfonyás (KK) and below the pond (KÁ).

Nagyberki stream is situated in the Somogy hills. It springs in a little wood-patch above Ecseny and flows into the river Kapos at Nagyberki. Not far from the mouth the stream swells into a little fishpond. We were there on 3 October 2003. The riverbed was dry around the spring, thus we could not take samples there. After 13 kms, around the settlement Büssü, there was enough water in the riverbed to take samples (NB) and we also took samples at the mouth (NT).

Conductivity, dissolved oxygen, pH, water temperature were measured in each case at the sampling points with a Multiline P4 F/SET–3 machine. Nitrate-nitrogen, ammonium-nitrogen and orthophosphate content were measured in the laboratory. Nitrate content was determined with the salicilite method according to Felföldy (1987) (colourimetric method). Phosphate content was determined with ammonium-molibdenate reagent and 10% ascorbic acid according to Felföldy (1987) (colourimetric method). Ammonium content was measured according to the ISO standard. Each measurement was carried out using filtered water (pore size: 0.45 µm).

The periphyton samples were scratched off from the surface of stones, in five replicates. The surface values were known. We used the CEN standards in the sampling and sample preparation. The samples were divided into two subsamples. One part of the sample was used to measure the chlorophyll-a content based on the method of Goodwin (1976). The other part of the sample was treated with H₂O₂, washed three times with distilled water, mounted in Naphrax and examined by light microscopy. The diatom indices were calculated with Omnidia Version 3 (Lecointe et al., 1993, 1999).

Some other diatom features – determined with the programme Omnidia – were taken into consideration when evaluating the data, such as tolerance and sensitivity (on the basis of sensitivity and relative abundance of very tolerant species in the samples according to Lange-Bertalot), some autecological characteristics (relative abundances of eutrophic, nitrogen heterotrophic, polisaprobic, alkalophilic species and species with high oxygen demand in the samples, according to van Dam et al.), as it was also recommended and applied by Fore et Grafe (2002) in the USA in the course of studying RDI (river diatom index).
RESULTS AND DISCUSSION

The measured physico-chemical parameters are also shown in Table 1. The values indicating either good or very good water quality on the basis of the water quality limit system (Szántó 1998) are in bold script. On the basis of the different nitrogen forms, the water quality is very good or good at most sampling sites, however, on the basis of phosphorus content the water quality does not seem to be so ideal. As an effect of a trout farm, the inorganic nutrient concentration of stream Szalajka increases considerably, and it is also high near Dédestapolcsány and the mouth of the stream Bán. The inorganic nutrient content has its lowest values around the source of stream Bán, stream Kemence as well as in stream Szén. The impact of human settlements is strongly detectable in stream Morgó, the nitrogen and phosphorus content increases considerably on the stretch below Szokoly. Stream Nagyberki has the usual fate of lowland streams, which means that the inorganic nutrient content is very high. We also measured the highest conductivity values in this stream, which supports the fact of high pollution load. The low conductivity values of streams Kemence and Szén also indicate that the water of these streams is clean. To sum up, we can state that the lowest values of conductivity and inorganic nutrient concentration were measured around the sources of streams Bán and Kemence and the upper stretch of stream Morgó (it is stream Szén). On the basis of these results, these stretches can function as reference sites.

We can get a more sophisticated picture about the water quality of streams with the aid of biological parameters, since benthic diatoms adapt to local environmental conditions inevitably on a longer time scale because of their attached lifeform. This is one reason why they indicate more dynamically the quality of the water. Around the source of the stream Szalajka e.g. low phosphorus and nitrate concentrations were measured, but the high ammonium concentration suggests that the stream is not utterly free of pollution, which is caused first of all by the busy tourist traffic. The large percentual proportion (92.5%) of *Achnanthidium minutissimum* (Kütz.) Czarnecki is also well in accordance with the fact of significant disturbance (Fig. 1). This diatom is a cosmopolitan species with a wide ecological valence. According to the literature, the presence of 0–25% of this species in a river indicates no disturbance, 25–50% indicates low, 50–75% intermediate, 75–100% high disturbance level (Stevenson and Bahls 1999). The high (196,4 µm) chlorophyll content also shows deteriorated water quality (Fig. 1). According to Dodds *et al.* (1998), higher than 20 µg cm⁻² a chlorophyll content of the benthos indicates eutrophic water quality. In his categorisation, the water is oligotrophic up to a chlorophyll concentration of 7 µg cm⁻², and mesotrophic between 7 and 20 µg cm⁻² values. On the basis of this system, Bán stream is oligotrophic around its source, which supports
Table 1
The measured physico-chemical parameters. (Abbreviations: see text)

<table>
<thead>
<tr>
<th></th>
<th>SzF</th>
<th>SzA</th>
<th>BF</th>
<th>BD</th>
<th>BT</th>
<th>Sz</th>
<th>MSz</th>
<th>MK</th>
<th>NB</th>
<th>NT</th>
<th>KF</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$-N mg l$^{-1}$</td>
<td>0.007</td>
<td>0.094</td>
<td>0.033</td>
<td>0.039</td>
<td>1.696</td>
<td>0.076</td>
<td>0.216</td>
<td>0.336</td>
<td>1.58</td>
<td>0.19</td>
<td>1.3</td>
</tr>
<tr>
<td>NH$_3$-N mg l$^{-1}$</td>
<td>1.36</td>
<td>1.34</td>
<td>0.13</td>
<td>1.6</td>
<td>4.72</td>
<td>0.064</td>
<td>0.093</td>
<td>0.063</td>
<td>n.d.</td>
<td>0.178</td>
<td>0.001</td>
</tr>
<tr>
<td>PO$_4$-P mg l$^{-1}$</td>
<td>0.005</td>
<td>0.069</td>
<td>0.004</td>
<td>0.092</td>
<td>0.299</td>
<td>0.075</td>
<td>0.193</td>
<td>0.18</td>
<td>0.632</td>
<td>0.019</td>
<td>0.009</td>
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<td>pH</td>
<td>8.36</td>
<td>8.29</td>
<td>8.25</td>
<td>8.4</td>
<td>8.3</td>
<td>8.89</td>
<td>8.64</td>
<td>8.57</td>
<td>8.6</td>
<td>8.6</td>
<td>7.95</td>
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<tr>
<td>water temperature (°C)</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>14</td>
<td>12.5</td>
<td>12.7</td>
<td>13.9</td>
<td>14.8</td>
<td>21.6</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>dissolved oxygen mg l$^{-1}$</td>
<td>7.75</td>
<td>7.04</td>
<td>6.4</td>
<td>7.1</td>
<td>5.5</td>
<td>6.53</td>
<td>6.54</td>
<td>7.76</td>
<td>8.4</td>
<td>5</td>
<td>8.7</td>
</tr>
<tr>
<td>conductivity µS cm$^{-1}$</td>
<td>420</td>
<td>468</td>
<td>554</td>
<td>650</td>
<td>930</td>
<td>264</td>
<td>776</td>
<td>687</td>
<td>2070</td>
<td>825</td>
<td>105</td>
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</table>

Table 2
Other diatom features, calculated with the programme OMNIDIA – considered during the evaluation of the data. (Abbreviations: see text)

<table>
<thead>
<tr>
<th></th>
<th>SzF</th>
<th>SzA</th>
<th>BF</th>
<th>BD</th>
<th>BT</th>
<th>Sz</th>
<th>MSz</th>
<th>MK</th>
<th>NB</th>
<th>NT</th>
<th>KF</th>
<th>KK</th>
<th>KT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitive individuals (%)</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>0.6</td>
<td>4.5</td>
<td>1.2</td>
<td>0.8</td>
<td>0.7</td>
<td>3</td>
<td>6.3</td>
<td>22</td>
<td>24.5</td>
<td>9.2</td>
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<tr>
<td>Very tolerant individuals (%)</td>
<td>0</td>
<td>1.5</td>
<td>1.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0</td>
<td>2.4</td>
<td>9.4</td>
<td>18</td>
<td>29.9</td>
<td>13</td>
<td>18.2</td>
<td>1</td>
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<tr>
<td>Eutrophic species (%)</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>78.5</td>
<td>78.5</td>
<td>80.6</td>
<td>90.9</td>
<td>93.9</td>
<td>68.7</td>
<td>39.6</td>
<td>6</td>
<td>21</td>
<td>11.4</td>
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<tr>
<td>Nitrogen heterotrophs (%)</td>
<td>0.3</td>
<td>0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
<td>0</td>
<td>1.2</td>
<td>0.9</td>
<td>5.4</td>
<td>10.4</td>
<td>0</td>
<td>0</td>
<td>0.7</td>
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<tr>
<td>Polisaprobic species (%)</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
<td>0.2</td>
<td>2.1</td>
<td>4.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Alkaliphilic species (%)</td>
<td>5.8</td>
<td>86.8</td>
<td>78.1</td>
<td>79.8</td>
<td>83.2</td>
<td>81.6</td>
<td>90.9</td>
<td>95.8</td>
<td>83.7</td>
<td>65.7</td>
<td>10.4</td>
<td>59.4</td>
<td>13.9</td>
</tr>
<tr>
<td>Require high oxygen (%)</td>
<td>92.8</td>
<td>50.3</td>
<td>6.7</td>
<td>4.3</td>
<td>14.9</td>
<td>1.2</td>
<td>1.6</td>
<td>2.8</td>
<td>16.2</td>
<td>11.6</td>
<td>46.8</td>
<td>8.4</td>
<td>7.1</td>
</tr>
</tbody>
</table>
that it can be used as a reference site. Szén stream, which also has a good water quality on the basis of the chemical parameters, is eutrophic on the basis of the chlorophyll content (Fig. 2). The water quality of stream Nagyberki is also deteriorated on the basis of the high chlorophyll content (Fig. 3), which was the highest among the investigated sites. The categorisation of water quality on the basis of the chlorophyll-a content of the benthos in a surface unit area could be a new element in the Hungarian water quality analysis, it is conceivable that limit values of the system determined by Dodds et al. (1998) for the quality analysis of American rivers needs some adjustment, but on the basis of these examples statuated here it seems that these limits are also applicable for the quality analysis of Hungarian rivers. On the stretch of the stream Kemence below Áfonyás pond, the ratio of *Achnanthis minitissimum* was higher than 50% (69.7%), which indicates intermediate disturbance level on this stretch of the stream. The other stretches of the river did not show any signs of disturbances (Fig. 4).

On the basis of the diatom features investigated in accordance to the recommendation of Fore and Grafe (2002), the water quality of streams Szalajka

![Fig. 1. Changes of conductivity, relative abundance of *Achnanthis minitissimum* (AMIN%), species number, diversity, evenness and some diatom indices in stream complex Szalajka-Bán (SzF = stream Szalajka close to the source, SzA = stream Szalajka below the trout farm, BF = stream Bán close to the source, BD = stream Bán at Dédestapolcsány, BT = stream Bán at the mouth, VG = very good, G = good, S = moderate, B = poor, VB = bad water quality)](image-url)
and Bán was good near the sources and so was that of stream Kemence along the whole investigated stretch (Table 2).

Species number, Shannon diversity and evenness values of benthic diatoms did not reflect the changes of the water quality (Figs 1–4). This is, however, not surprising, since the species composition of benthic diatoms grows richer alongside rivers, according to the impact of inflowing sidearms (Szabó et al. 2004).

Among the Omnidia indices, the indices EPI-D, IPS and IBD indicated the changes of water quality best. On the basis of EPI-D, the water quality of Szalajka and Bán streams are good near the sources; below the sources it is acceptable. According to IPS, water quality of stream Szalajka is very good near the source, good below the source, water quality of stream Bán is good on the whole investigated stretch. On the basis of IBD, water quality of stream Szalajka is very good near the source, acceptable on the lower stretches; water quality of stream Bán is acceptable at every sampling point (Fig. 1). The upper and middle stretch of stream Morgó was of acceptable, close to the mouth of bad water quality on the basis of EPI-D, the upper and middle stretch was of

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**Fig. 2.** Changes of conductivity, chlorophyll concentration, relative abundance of *Achnanthes minutissimum* (AMIN%), species number, diversity, evenness and some diatom indices in stream complex Szén-Morgó (Sz = stream Szén, MSz = stream Morgó below Szoko-lya, MK = stream Morgó at Kismaros, other abbreviations see in Figure 1)
good, close to the mouth of acceptable water quality according to IPS, whereas on the basis of IBD it was acceptable everywhere (Fig. 2). The water quality of stream Nagyberki was bad at both sampling points according to the EPI-D, acceptable according to IBD and it was acceptable near Büssü and bad close to the mouth on the basis of IPS (Fig. 3). Stream Kemence was of good water quality on the basis of EPI-D, it was very good near the source and good on the lower stretches according to IBD, it was very good near the source and below the pond and good before the pond on the basis of IPS (Fig. 4). The fact that almost all parameters (both chemical and biological) indicate good water quality of the stream, there are no larger settlement situated alongside of the river from the source to the mouth. Furthermore, it flows almost exclusively on the area of the Zemplén landscape protection area, consequently no significant human disturbance has to be taken into account. Thus, this stream is in any case suitable as a reference for highland, volcanic rivers. The separation of the places with the best water quality (stream Szalajka around its source and the total length of the stream Kemence) is also well discernible on the dendrogram (Fig. 5) of the cluster analysis based on the relative abundance values of the species. All three indices showed either good or very good water quality at these sampling points. Stream Szalajka around the source and stream Kemence...
ce after the Áfonyás pond grouped together because of the high *Achnanthidium minutissimum* (92.5% and 69%) dominance. At the latter site, the species *Gomphonema micropus* Kg. dominated, too. *Achnanthidium minutissimum* also dominated (10%) around the source of the Kemencés stream, however, it did not reach the lower limits of disturbance. The species *Diatoma mesodon* (Ehr.) Kg., *Gomphonema micropus* and *Gomphonema pumilum* (Grun.) Reichardt et Lange-Bertalot also dominated. On the stretch above the Áfonyás pond, the species *Fragilaria ulna* (Nitzsch.) Lange-Bert., *Gomphonema microporum*, *G. pumilum*, *Meridion circulare* (Grevile) Agardh, *Navicula lanceolata* (Agardh) Ehrenberg és *Nitzschia linearis* (Agardh) W. Smith reached a relative abundance of at least 5 percent. The samples from around the source of the Bán stream and from the Szén stream were grouped together on the dendrogram, too. Generally, good water quality is characteristic of these places, too. In stream Bán, around the source the species *Amphora pediculus* (Kütz.) Grun., *Cocconeis placentula* var. *euglypta* Ehr., *Gomphonema micropus*, *Planothidium lanceolatum* (Bréb.) Round et Bukhtijarova, *Reimeria uniseriata* Sala Guerrero et Ferrario, in stream Szén *Cocconeis placentula* var. *euglypta*, *Gomphonema pumilum*, *Nitzschia inconspicua* Grun.,

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Fig. 4. Changes of conductivity, relative abundance of *Achnanthidium minutissimum* (AMIN%), species number, diversity, evenness and some diatom indices in stream Nagyberki (KF = close to the source, KK = at Kókapu, before pond Áfonyás, KA = below pond Áfonyás, other abbreviations see in Figure 1)
Planothidium lanceolatum, Rhoicosphenia abbreviata (Ag.) Lange-Bert. dominated. The stretch of stream Nagyberki around the spruce separated strongly. This sampling point had the worst water quality in this investigation, it also receives the water of the local fishing pond, which is also shown by the presence of planktonic Centrales species (the relative abundance of them reached 20.9%, whereas at the other sampling points they were not present at all or only in low relative abundance –1–3%). Gomphonema parvulum Kütz., which – as it is well-known – indicates deteriorated water quality. Moreover, Navicula cryptotenella Lange-Bert. and Nitzschia subacicularis Hustedt, which are both tolerant for the level of inorganic nutrient supply (van Dam et al. 1994) were only dominant at this sampling point. The water quality of the rest of the sampling points could mostly be characterised as moderate. These were also grouped together on the dendrogram: the stretch of stream Szalajka below the trout pond where the species Achnanthidium minutissimum, Amphora pediculus, Cocconeis placentula var. euglypta and Staurosirella pinnata (Ehrenberg) Williams et Round were strongly dominant, stream Bán near Dédestapolcsány and the mouth, stream Morgó near Szokolya and the mouth, stream Nagyberki near Büssü, with Amphora pediculus being strongly dominant (more then

![Dendrogram of cluster analysis prepared by UPGM fusion method, Bray-Curtis similarity index. In the matrix, relative abundance values of diatoms were included. (Abbreviations: see text)](image)
36% at all of these points) on these latter sampling points. In stream Bán near Dédestapolcsány and the mouth Cocconeis placentula var. euglypta and at the latter point Achnanthes petersenii Hustedt were also dominant. In stream Mórgó below Szokolya Eolimna minima (Grunow) Lange-Bertalot, Nitzschia amphibia Grunow and Nitzschia inconspicua were present in a relative abundance higher than 5%, at the mouth these species were Cocconeis placentula var. euglypta, Nitzschia inconspicua and Rhoicosphenia abbreviata. In stream Nagyberki near Büssü the formerly mentioned Amphora pediculus, furthermore Navicula Schroeterii Meister and Planothidium lanceolatum were dominant.

REFERENCES


